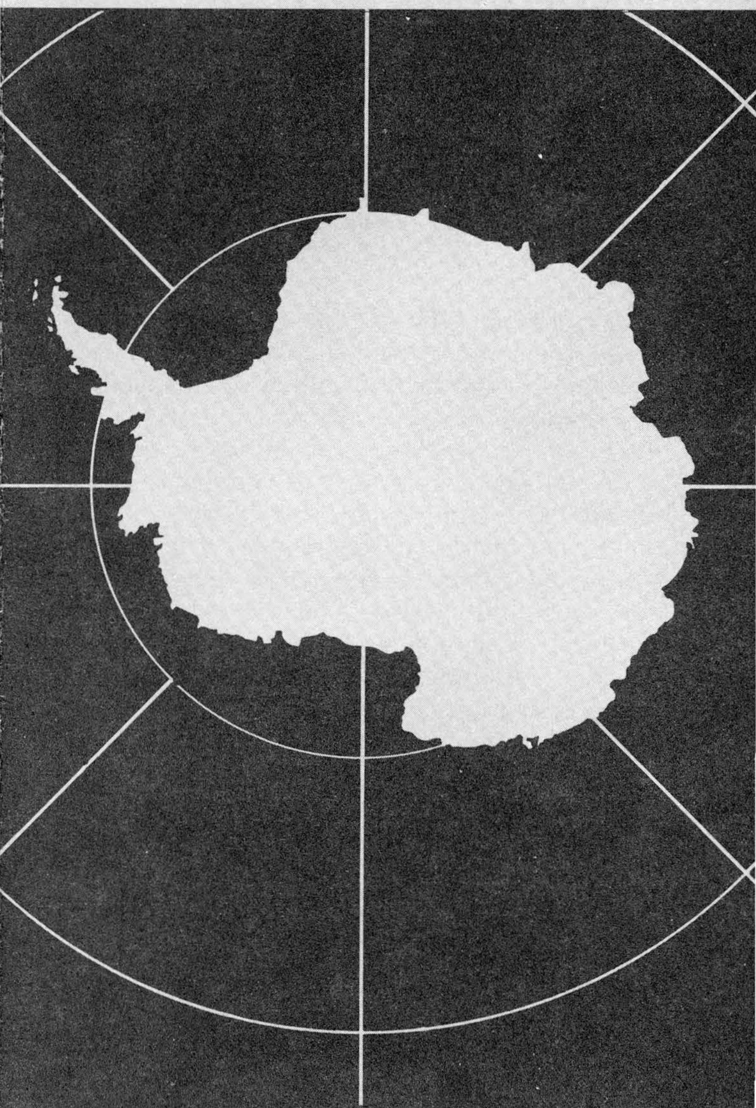
The Antarctic and Its Geology



United States Department of the Interior/Geological Survey

The Antarctic and Its Geology

by A. B. Ford and D. L. Schmidt

To the seamen of the 18th century who skirted its ice-choked seas in their wooden vessels, Antarctica was known as "Terra Australis Incognito"—the unknown land of the south.

Who first saw Antarctic lands is uncertain. On November 17, 1820, Nathaniel Palmer, captain of a Connecticut fur-sealing vessel, almost certainly sighted the continent and in his logbook mentioned seeing land.

On the first official U.S. Government expedition to Antarctica in 1838, Navy Lieutenant Charles Wilkes found erratic blocks of continental-type rocks—granite and sandstone. These rocks, carried far northward by floating icebergs, pointed to the existence of large south polar continent. Today part of Antarctica is called Wilkes Land in his honor.

Pioneer explorations of the continent itself by Sir Ernest Shackleton, Captain Robert F. Scott, Roald Amundsen, Sir Douglas Mawson, and many others began in 1901. Many thrilling stories have been told about this "heroic age" of Antarctic discovery.

Americans did not become prominent in Antarctic exploration until later. Rear Admiral Byrd was the first to use the airplane, tractor, and radio extensively in the continent, and his expedition in 1928-30 included the first flight over the South Pole. Another American aviator, Lincoln Ellsworth, flew across the continent in 1935 and surveyed from the air the area known as the American Highland.

Expeditions using modern technology inevitably became too expensive for private parties to undertake. The U.S. Government officially sponsored the Antarctic Service Expedition to the Antarctic Peninsula and Ross Sea areas in 1939-41, and also the massive aerial photographic mission, Operation Highjump, by the U.S. Navy under Admiral Byrd in 1946-47. These expeditions were followed the next season by Operation Windmill to establish ground control for map compilation, and by the Ronne Antarctic Research Expedition in the southern Antarctic Peninsula in 1947. The United States participated in many exploratory and scientific programs carried out during and since the International Geophysical Year of 1957-58.

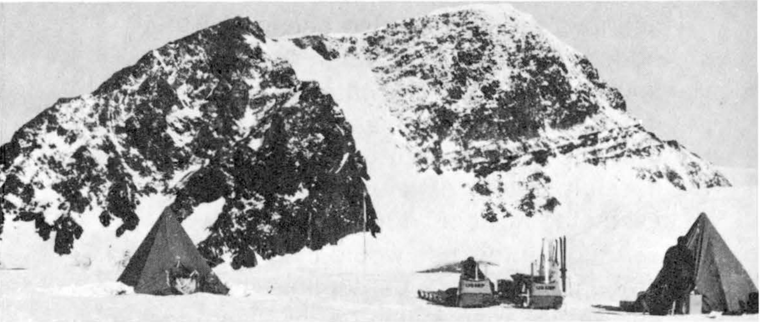
The continent gradually became a vast experiment in international scientific cooperation. In December 1959, the Antarctic Treaty was signed by 12 countries: Argentina, Australia, Belgium, Chile, France, Japan, New Zealand, Norway, the Republic of South Africa, the U.S.S.R., the United Kingdom, and the United States. They agreed to make no territorial claims for the duration of the treaty (30 years), to use the continent for peaceful purposes only, to open the operations of each country to inspection by any other nation, and to preserve and conserve Antarctic resources.

Many are surprised to learn that Antarctica is nearly twice the size of the United States. The name Antarctica was coined to mean "opposite to the Arctic," and it is just that in many ways besides its geographic position. Antarctica is a high, ice-covered landmass, whereas the Arctic landmasses are grouped around the ice-covered Arctic Ocean.

Largely because of this primary difference, the climates of the two regions are very different. Antarctica is the coldest area in the world, on the average about 30 degrees colder than the Arctic. At the South Pole, nearly 10,000 feet in elevation, monthly mean temperatures range from —13°F in the summer to —80° in the winter. Only in coastal regions do temperatures occasionally rise above freezing in the summer (December to March). In contrast, near the North Pole, at sea level, monthly mean temperatures range from +32° to —31°F. At both poles, daily temperatures may drop far below the monthly means; at Amundsen-Scott South Pole Station (U.S.A.), winter temperatures occasionally fall below —100°F. Elsewhere, on higher parts of the south polar plateau, even lower temperatures are recorded. At Vostok Station (U.S.S.R.), a temperature of —127°F was measured in August 1960, the world's record low temperature.

Partly because of this climatic difference, the land animal and plant populations of the two regions differ greatly. On the continent of Antarctica very little plant life exists, whereas in the Arctic it exists in abundance. In some of the few ice-free areas of Antarctica, mosses, lichens, or algae can be found. These are quite different from their northern counterparts. Penguins, the large but flightless birds that populate Antarctic coastlines, do not exist in the Arctic, whereas land animals of the Arctic—foxes, bears, reindeer, lemmings—are unknown in the Antarctic. As recorded by fossils in the old sedimentary rock layers, this "oppositeness" between north and south extends far back into the early chapters of Earth history.

Ice is the overwhelming feature of Antarctica. More than 4.5 million square miles of ice sheet cover the continent. Great rivers of ice, called glaciers, push down the mountain valleys. Shelves of ice surround the continent and stick out into the sea. Antarctica is the storehouse of about 85 percent of the total world supply of ice.



Survey field camp at base of exposed bedrock in the Transantarctic Mountains at 85° South Latitude. Large, prominent snow-filled gully marks steep fault, which truncates gently dipping beds on right.

The icecap is very thick, averaging between 7,000 and 8,000 feet. At one particular point, scientists have found the distance from the surface to the rock underneath the ice to be more than 13,000 feet.

A commonly asked question is: "What would happen if this incredibly great volume of ice were to melt?" Obviously, the volume of the world's oceans would increase, and sea level would rise.

However, the melted water is not the only factor to consider. The Antarctic icecap is one of the largest temporary loads upon the Earth's crust. In Pleistocene time, Scandinavia and Canada were sites of continental ice sheets, and studies in these countries show that when the ice load was removed, the formerly depressed crust rose several hundred feet above present sea level. Evidence for this is found in elevated beach deposits containing marine fossils.

To understand why the continent rises when the ice load is removed, think of a full hot water bottle. If pressed down in one place, it bulges in another. If released the pressed-down area rises, but the area that had bulged up sinks down, and the whole surface evens out.

If the Antarctic ice load should melt, the depressed crust would rise. However, the sea level would also rise because of the added volume of meltwater. In turn, the increased load of seawater would probably depress the crust beneath the ocean basins. If all these effects are taken into account, the possible sea-level rise can be roughly estimated at about 130 feet.

Although this rise would of course be very gradual and barely perceptible in terms of human life span, cities on low-lying coastal plains or reclaimed land below present sea level would be vulnerable.

A second question might be asked: "Was the ice sheet of the Antarctic continent ever thicker than today?" The answer is definitely "Yes." Evidence from mountaintops in many widely scattered areas in Anarctica demonstrates that the ice sheet was indeed once at least 1,000 feet thicker than it is now.

Because the thickness of the ice has altered in the past, it is well to ask: "Is the ice becoming thinner or thicker at the present time?" Recent glaciological data suggest that at present the ice level is rather stable and probably is not shrinking. However, much more glaciological study is necessary before we know whether small changes in ice thickness are taking place today.

Antarctica has not always been the home of the blizzard. Plant and animal fossils show that the continent once had a temperate climate. For example, during late Paleozoic time luxuriant forests grew, as is evident from coal deposits found in the Antarctic. Some of these coal deposits are less than 300 miles from the South Pole. But one and perhaps several ancient glacial epochs have interrupted the temperate epochs. All Southern Hemisphere landmasses—the now subtropical parts of South America, Africa, and Australia, as well as peninsular India—have had similar glacial epochs. The ancient glacial deposits, called *tillites,* have no counterpart of similar age in the Northern

Hemisphere, again demonstrating the oppositeness of north and south polar regions.

Plant fossils in the Antarctic Peninsula show that for much of the Tertiary Period the climate was probably temperate. Certainly it was much warmer than it is today. During the Tertiary Period, forests of beech trees grew where today only lichens, mosses, algae, and a few very rare varieties of grasses can exist. Not until quite recently, geologically speaking, did climatic changes produce the present-day icecap. Glacial advance probably began at the end of the Tertiary Period or the beginning of the Quaternary Period, that is, about 1 to 5 million years ago.

Glacial epochs occurred in similar fashion in the north, but whether they were synchronous with those in the Southern Hemisphere is questionable.

If the tremendous ice cover could somehow be removed, how would Antarctica look? The appearance of the actual land surface of Antarctica has long been a matter of debate. Only recently have geophysical studies provided a fairly accurate picture of the continent below the ice (fig. 1).

For many years, Antarctica was thought to be only an archipelago whose islands were tied together above sea level by ice. As recently as the 1950's, it was thought to be made up of two small subcontinents—East Antarctica, the larger, and West Antarctica, containing the Antarctic Peninsula. The two continents were supposed to be separated by a large trough, below

Era	Period	Estimated age (millions of years)
CENOZOIC	Quaternary	1
	Tertiary	70
MESOZOIC		230
PALEOZOIC		600
PRECAMBRIAN		3,000+

Table 1. Major time divisions in the history of the Earth.

sea level, that connected the Ross and Weddell Seas.

Geophysical studies have now revealed a fairly complete picture of the Antarctic landform below its ice cover. We know now that West Antarctica is connected to the main part of the continent by a chain of mountains well above sea level, though largely buried by ice and snow. However, the mountains of Marie Byrd Land are a large island mass surrounded by ice extending well below sea level. The bedrock of much of East Antarctica appears to be above sea level. Some of it, in the high ranges of the Transantarctic Mountains and in Queen Maud Land, is far above sea level.

Whether mineral wealth lies hidden by the vast ice sheets is unknown. No more than 2 percent of the continent is actual rock outcrop and much of this small and probably

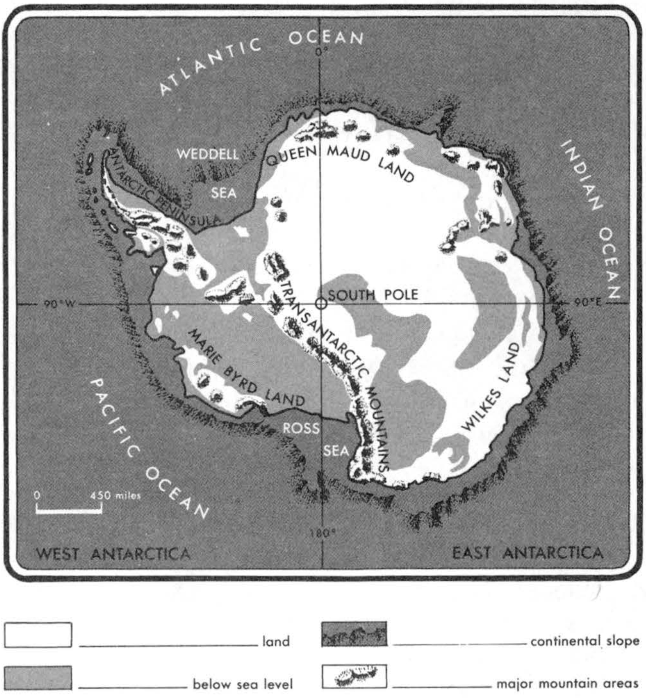


Fig. 1. Physiographic diagram of Antarctica without its ice.

unrepresentative sample has yet to be visited by geologists. Certainly, no deposits rich enough to be economically useful have been found.

Geologist now know that the largely ice-buried rocks of the Antarctic are similar to rocks of the other continents of the world. There have been reported at least minor amounts of potentially valuable minerals such as cassiterite (tin oxide), galena (lead sulfide), stibnite (antimony sulfide), molybdenite (molybdenum sulfide), sphalerite (zinc-iron sulfide), and copper minerals, as well as traces of gold and silver. The presence of petroleum has been speculated upon by several geologists, but none has yet been found. Low-grade deposits of coal are widespread, especially in the Transantarctic Mountains, but there has been no attempt at exploitation. Even if rich mineral deposits were to be found in Antarctica, except in a few areas the cost of removal from this remote and inhospitable land would be exorbitant.

Interpretation of continental structure is an important objective of any extensive geologic investigation. Yet except for the Earth's ocean basins, no area the size of Antarctica is so geologically unknown. With 98 percent of the continent covered by ice, it is extremely difficult to decipher the general structure. Geologists determine geologic structure by studying rock outcrops, and many of these are small and widely separated *nunataks* (an Eskimo word for a small bedrock "island" in a "sea" of ice). No outcrops are known in the vast interior of East Antarctica.

Working out the continental structure of Antarctica is analogous to learning that of the entire United States from studies of a few scattered counties in California and mountain ranges scattered at irregular intervals across the country. In short, whole structural provinces may well lie entirely hidden by ice. Geological interpretation of

Antarctica without extensive sub-ice rock sampling will always be open to great uncertainty.

Most of East Antarctica was early recognized to be a large ancient shield region, composed of old basement granites and metamorphic rocks locally overlain by very thick, mostly flat-lying sandstones and related sedimentary rocks. Along the Transantarctic Mountains the youngest fossils found in the strongly folded basement rock are called "Archeocyathids." These cup-shaped, sponge-like organisms are of early Paleozoic age (about 500 million years old). The oldest fossils in the overlying flat-bedded sandstones are middle Paleozoic (about 400 million years old) fish remains and shells of clams and brachiopods.

So far as is known, no sedimentary rocks in this mountain belt represent the portion of geologic time from 400 to 500 million years ago. This gap in the sedimentary record is called an *unconformity* by geologists. The unconformity represents a time when the previously deposited rocks were being folded, altered by metamorphism, intruded by granite, and uplifted to form ancient mountains. These mountains were eventually

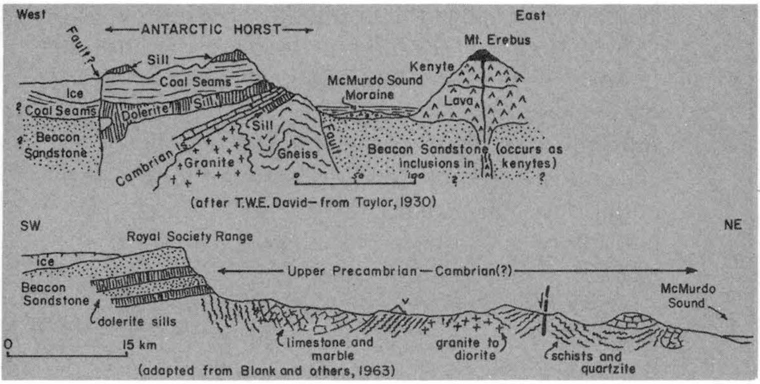


Fig. 2. Two diagrammatic cross sections showing the geologic structure through the Transantarctic Mountains and eastern foothill belt. Above, classic 1930 interpretation and below, 1963 interpretation. Vertical scale greatly exaggerated.

worn down by erosion. By middle Paleozoic time they were covered by seas, and new deposits of sand and mud were laid down on the folded older rocks (see fig. 2).

The crust of East Antarctica seems to have been inactive since this early Paleozoic time of mountain building (called *orogeny* by geologists). The known sedimentary deposits laid down since the orogeny have mostly remained in their original flat-lying position. However, they have been uplifted along large faults (see fig. 2).

In contrast, the crust of much of West Antarctica has been highly mobile through the Paleozoic and Mesozoic Eras and into the Cenozoic (recent life) Era in places. This is demonstrated by the great thicknesses of poorly sorted sediments—tens of thousands of feet—that accumulated in submarine basins. The rocks composed of these sediments were later intensely folded and contorted, intruded by molten granite, and eventually uplifted as mountain ranges.

The evidence of fossils suggests that such mountain building occurred several times in West Antarctica's history. Eruptions of volcanic materials were perhaps surface phenomena related to mountain-building events deeper in the crust. Crustal mobility in the northern end of the Antarctic Peninsula at the present time is indicated by volcanism and earthquake activity.

The structural pattern of Antarctica is strikingly similar to that of the other continents that bound the Pacific Ocean basin. West Antarctica, the Andes of South America, the Coast Range of North America, the islands of Japan, New Guinea, and New Zealand are all young mobile belts that lie between the Pacific basin and old, rigid continental shields (see fig. 3). Indeed, the geology of the Antarctic Peninsula shows its long and narrow mountain backbone to be a continuation of the South American Andes. They are apparently connected by the island-dotted submarine ridge that bounds the Scotia Sea.

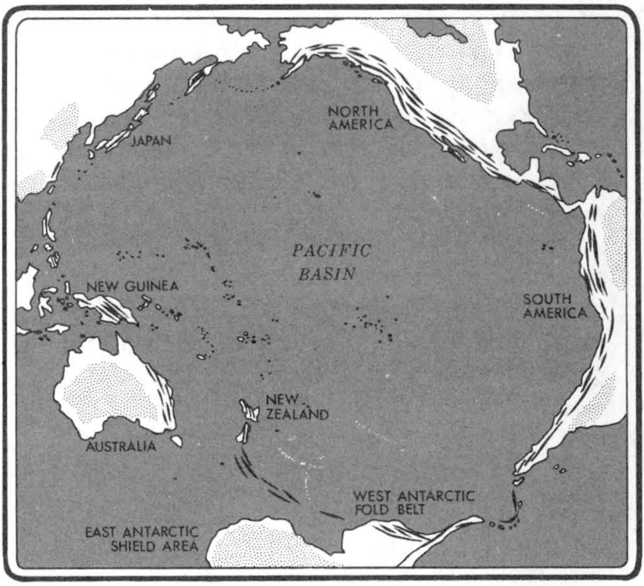


Fig. 3. Sketch map showing relatively young circum-Pacific mobile belt (lines) that separated Pacific basin from older shield areas (dot pattern) of continents.

Because of the close resemblance, these peninsular mountains have on occasion been referred to as the "Antarctandes." The young mobile belt of West Antarctica is believed to extend northwestward by way of a known submarine ridge to connect with New Zealand. Thus Antarctica completes the picture of a young mobile belt, dotted with active or recently active volcanoes, entirely encircling the rim of the Pacific.

Field studies in Antarctica, including those of the U.S. Geological Survey, are coordinated and financed by the National Science Foundation through its U.S. Antarctic Research Program (USARP). Logistic support for the field studies is provided by the U.S. Navy through its Operation Deep Freeze. Helicopter support for some projects is now provided by the U.S. Army.

Geology is an extremely important part of the program. Approximately one-fourth of all Antarctic field projects each year are in the fields of geology and geophysics. In

Folded sedimentary rocks of Precambrian age in isolated mountain range about 500 miles from the South Pole.

addition to fieldwork by the Geological Survey, several universities are engaged in geologic projects in Antarctica.

The Survey's program in the Antarctic is varied. Projects range in scope from reconnaissance studies by individual geologists to large-scale geologic mapping of remote mountain ranges by teams of geologists. Individual geologists accompany icebreakers along unexplored coasts or take part in oversnow traverses of the vast interior icecaps. The geologic mapping parties lead a nomadic life in which the geologist camp in two-man tents from day to day at the rock area being mapped. A permanent hut is constructed as a central base of supplies. Within the map area, motor toboggans are used for transportation. Each toboggan pulls about 2,000 pounds of tents, food, fuel, equipment, and rock specimens. Field parties work during the Antarctic summer from about November to March when the temperature averages near 0°F but may reach a comfortable summertime high at 20°F. During this season the cruel winds abate somewhat.

The Geological Survey is also actively engaged in the preparation of topographic maps of many parts of the Antarctic continent. Maps are critically needed for all scientific investigations in the Antarctic, to say nothing of their value to future Earth and space navigation. As the Antarctic becomes better known, the maps must become more detailed and precise. Each year field engineers accompany geologic, geophysical, and glaciological parties in previously unvisited regions to obtain geodetic control for the

Outlet rivers of ice from the polar plateau flow through the Transantarctic Mountains to reach the sea. Locally, mountains—nunataks—are entirely surrounded by glacial ice as in center of photo.

compilation of maps from aerial photography provided by the U.S. Navy. In recent years mapping control has been attained over enormous areas of otherwise highly inaccessible mountain terrain by use of helicopters and sensitive electronic distance-measuring instruments.

Whatever the mineral resource potential of Antarctica may be, the continent's greatest export is still scientific data. What kind of rocks compose the continent? What is the geologic history of Antarctica? Will the icecap melt? Is it expanding or contracting? In the great Antarctic laboratory, Survey scientists are hoping to learn some of the Earth's best kept secrets.

Ross Island, composed of three volcanoes (left to right): Mounts Bird, Erebus, and Terror. Note plume of smoke from crater of Erebus (1). Main U.S. Antarctic base, McMurdo Station, is seen at front of long peninsula (2).

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